NA61 incident pion for PPFX

pi + C → pi + X

Nilay Bostan (Ulowa)

For PPFX group meeting

Feb 5/2021

Introduction
What is our strategy?

- **Fine interpolation of the data (θ, P):**

1) We use a covariance matrix to generate "many universes" (new data).

2) NA61 has not released a correlation matrix. We are preliminary assumption (50%) while we will contact the authors for their input.

3) Currently working to improve the interpolation technique. (Antoni Aduszkiewicz is working on this improvements)

- **Making PPFX input:**

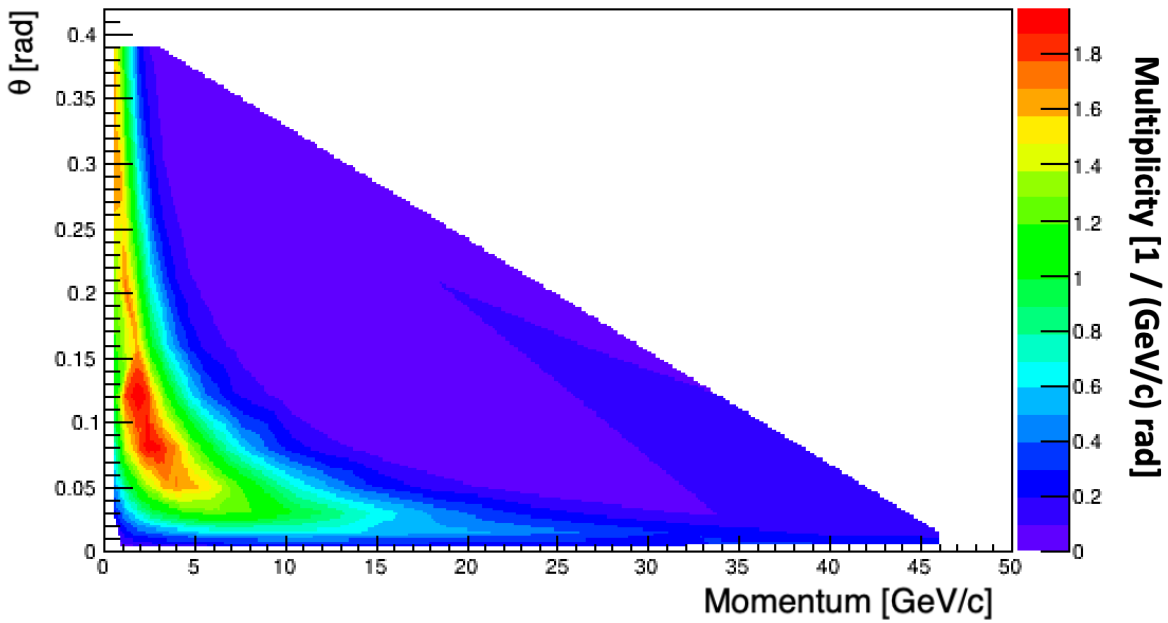
1) Calculating <f(xf,pt)> to n(P, θ)

2) We will use Feynman scaling to go from 60 GeV to 12-60 GeV.

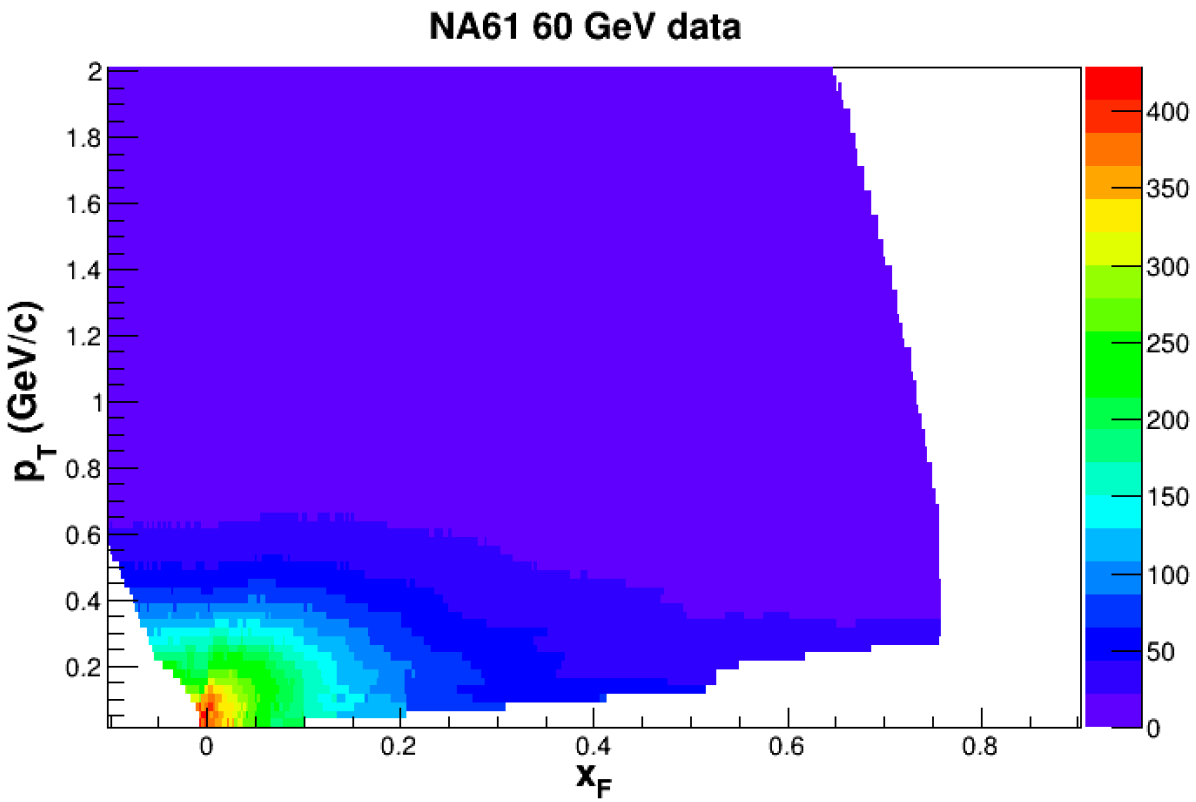
3) I am generating incident pion on carbon for energies: 12, 16, 20, 25, 30, 35, 40, 45, 50, 55, 60, 100 GeV for QGSP_BERT and FTFP_BERT.

4) We will use FLUKA to correct any scaling violation.

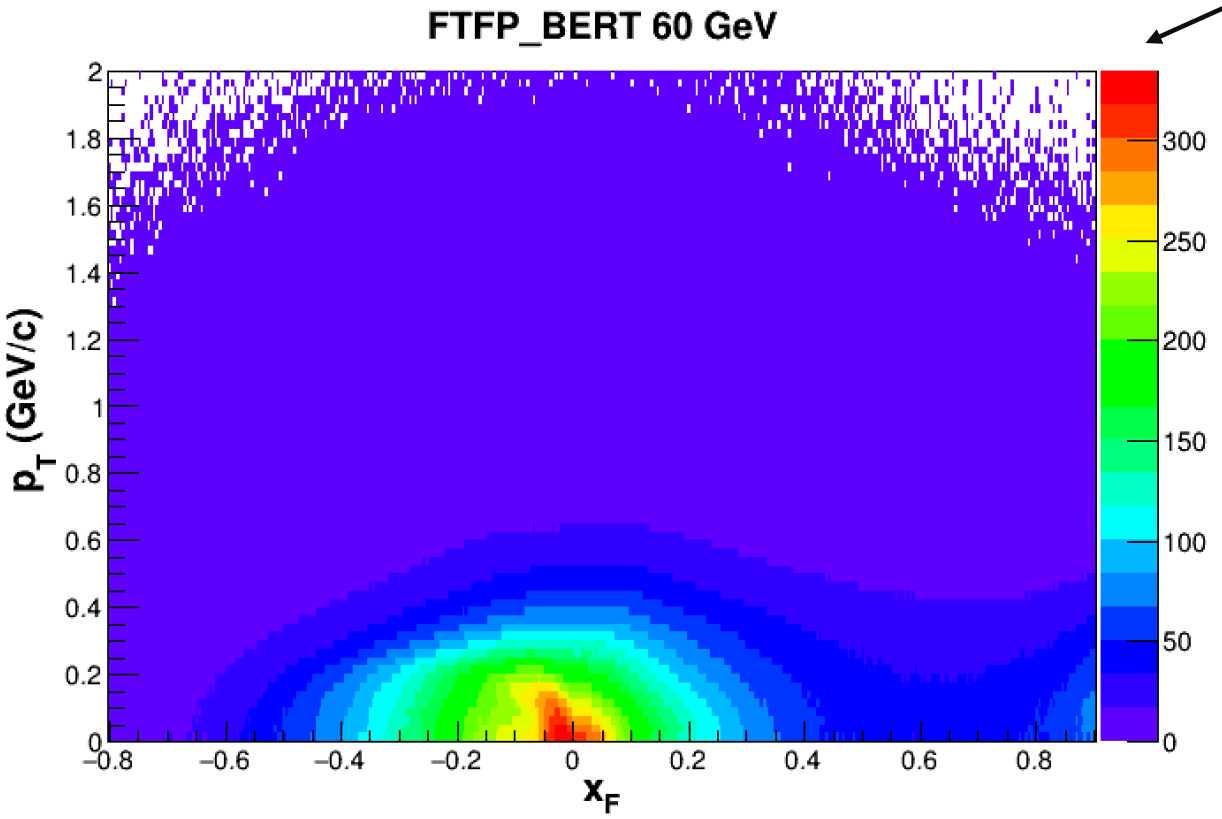
interpolated NA61 data, CV in universe 1000 (by using linear interpolation) :

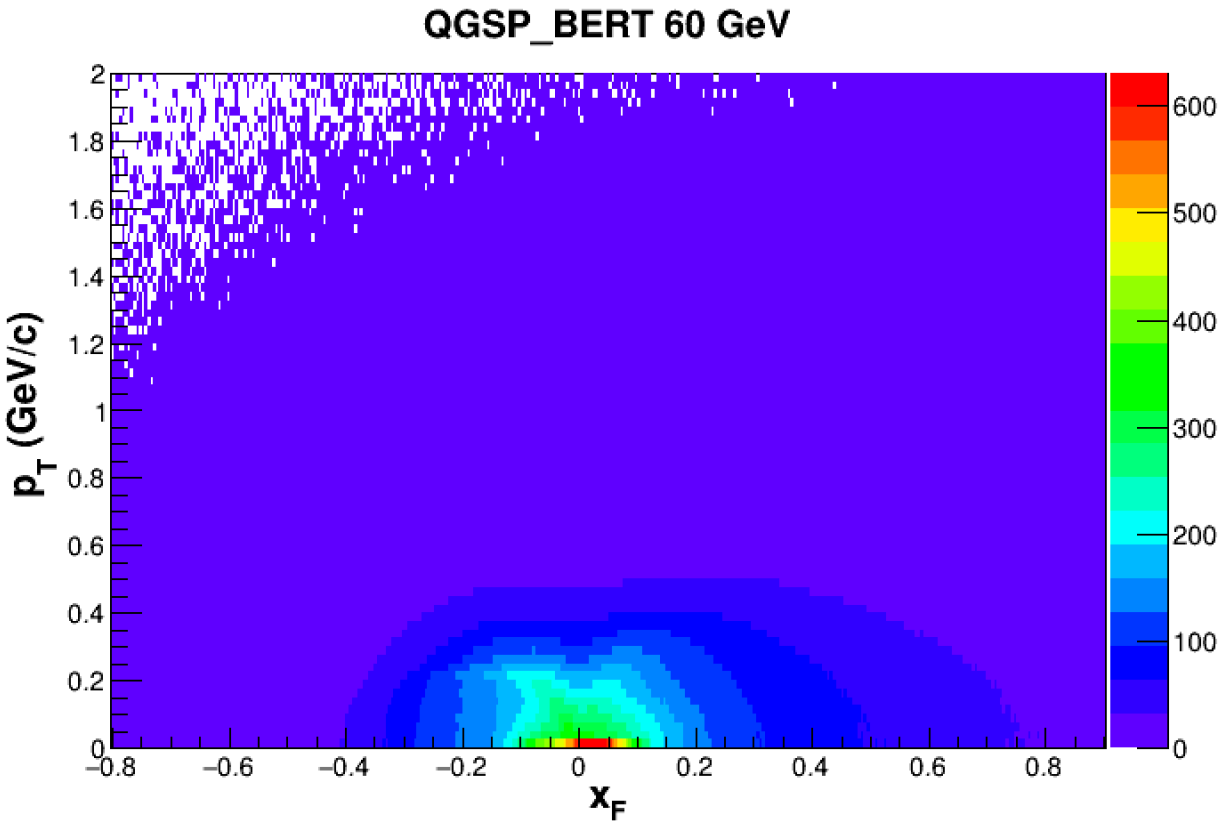


invariant cross-section for NA61 60 GeV interpolated data (linear interpolation) :



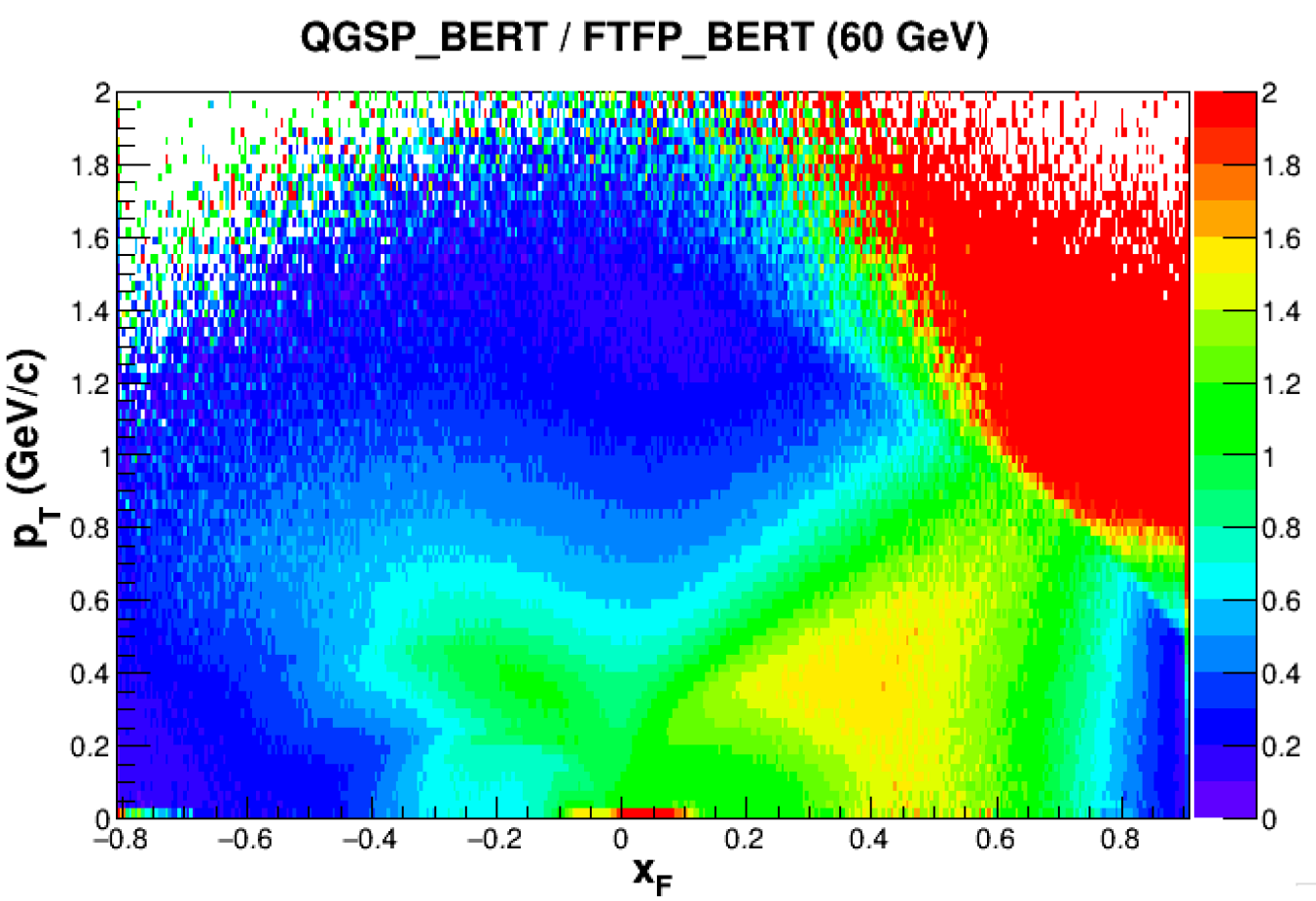
Invariant cross-section for FTFP_BERT and QGSP_BERT





Let`s take their ratio:

Invariant cross-section ratio for QGSP_BERT and FTFP_BERT



Conclusions

- **In this talk, I showed the invariant cross-section results for NA61 60 GeV interpolated data (linear interpolation) and QGSP_BERT & FTFP_BERT.**

- **We are currently working with Antoni to improve the interpolation technique.**

Thank you very much for listening!

Any comments and/or suggestions are welcome!!!

Backup

Definitions:

Measurements of bin-integrated cross sections of charged-pion produced in proton-carbon interactions at 31 GeV were released in [4]. The bin are in terms of the momentum (P) and the angle (θ) with respect to the beam direction. The results are $g = \frac{1}{\Delta P}\sigma(p,\theta)$ and they can be related to the invariant cross section:

$$\begin{aligned} g &= \frac{1}{\Delta P}\int\int\int d^3\sigma \\ &= \frac{1}{\Delta P}\int\int\int \left[\frac{1}{E}\right]\underbrace{\left[E\frac{d^3\sigma}{dp^3}\right]}_{f} dp^3. \end{aligned} \tag{9}$$

The bin content g of $[P_{low}, P_{high}]$ and $[\theta_{low}, \theta_{high}]$ divided by the P bin size is:

$$g([P_{low}, P_{high}], [\theta_{low}, \theta_{high}]) = \frac{1}{\Delta P}\int_{P_{low}}^{P_{high}}\int_{\theta_{low}}^{\theta_{high}}\int_0^{2\pi}\frac{1}{E}f(x_F, p_T)p^2 sin\theta dp d\theta d\phi. \tag{10}$$

The average invariant differential cross section, $< f >$, weighted by the inverse energy of the outgoing particle in the interaction is given by:

$$\langle f(x_F, p_T)\rangle = \frac{\int_{P_{low}}^{P_{high}}\int_{\theta_{low}}^{\theta_{high}}\int_0^{2\pi}\frac{1}{E}f(x_F, p_T)p^2\sin\theta dp d\theta d\phi}{\int_{P_{low}}^{P_{high}}\int_{\theta_{low}}^{\theta_{high}}\int_0^{2\pi}\frac{1}{E}p^2\sin\theta dp d\theta d\phi}. \tag{11}$$

The denominator (D) in Eq. 11 is

$$D = 2\pi\left[\cos\theta_{low} - \cos\theta_{high}\right]\left[\frac{p}{2}\sqrt{p^2+m^2} - \frac{m^2}{2}log\left(\sqrt{p^2+m^2}+p\right)\right]_{P_{low}}^{P_{high}}. \tag{12}$$

And then the $< f >$ can be calculated from the bin content as:

$$\langle f(x_F, p_T)\rangle = \frac{\Delta P g([P_{low}, P_{high}], [\theta_{low}, \theta_{high}])}{D}. \tag{13}$$

$\pi^+ C \to \pi^\pm X$

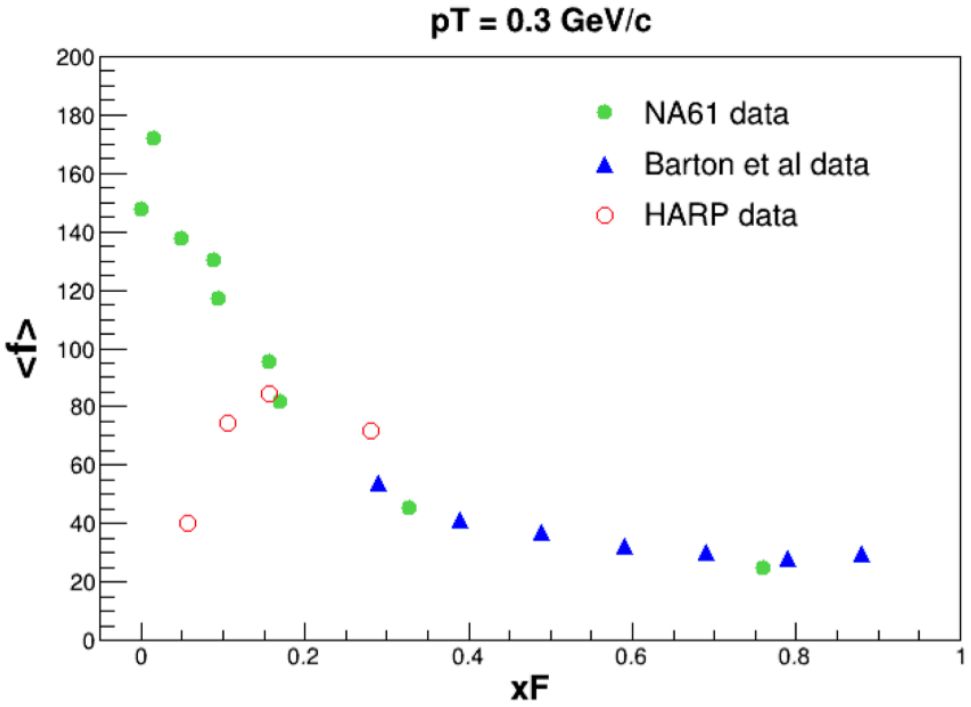
NA61 recently published integrated multiplicities of different particles in pion-carbon interactions at 60 GeV in terms of the P and θ with respect to the beam direction [6]. The results are s $k = \frac{1}{\Delta P \Delta\theta}n(p,\theta)$ can be related to the invariant cross section by using the production cross section (σ_{prod}), also measured in the paper:

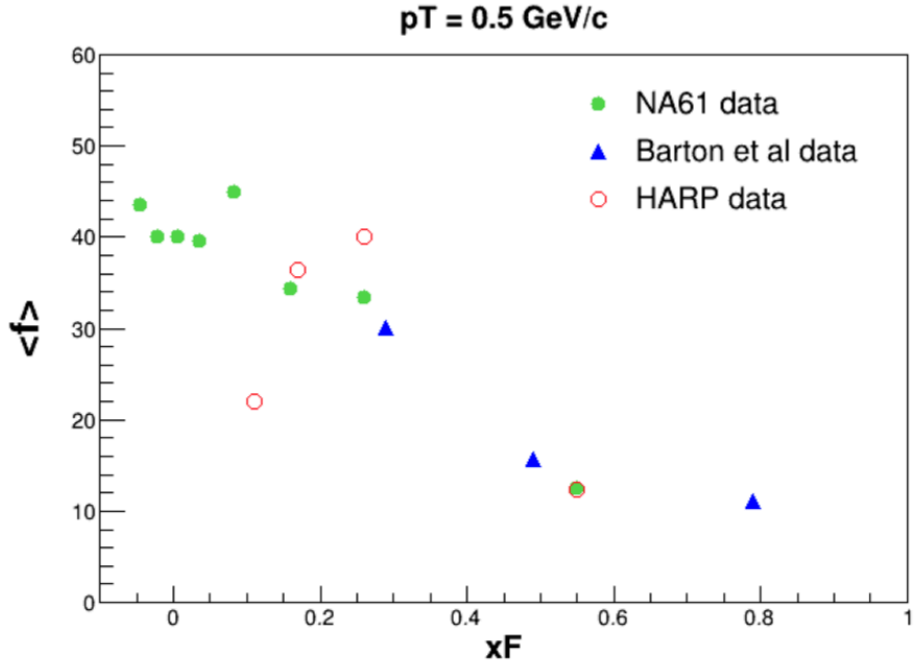
$$\begin{aligned} k &= \frac{1}{\Delta P\Delta\theta}\int\int\int d^3 n \\ &= \frac{1}{\Delta P\Delta\theta\sigma_{prod}}\int\int\int\left[\frac{1}{E}\right]\underbrace{[\sigma_{prod}]\left[E\frac{d^3n}{dp^3}\right]}_{f} dp^3. \end{aligned} \tag{15}$$

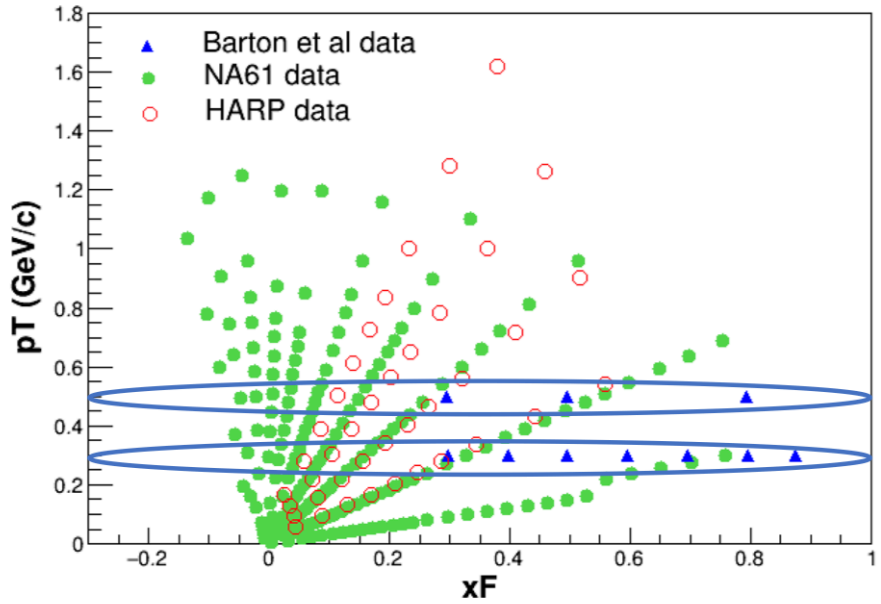
And then:

$$\langle f(x_F, p_T)\rangle = \frac{\Delta P\Delta\theta\sigma_{prod}k([P_{low}, P_{high}], [\theta_{low}, \theta_{high}])}{D}. \tag{16}$$

Invariant cross-section and xF comparisons for different datasets:

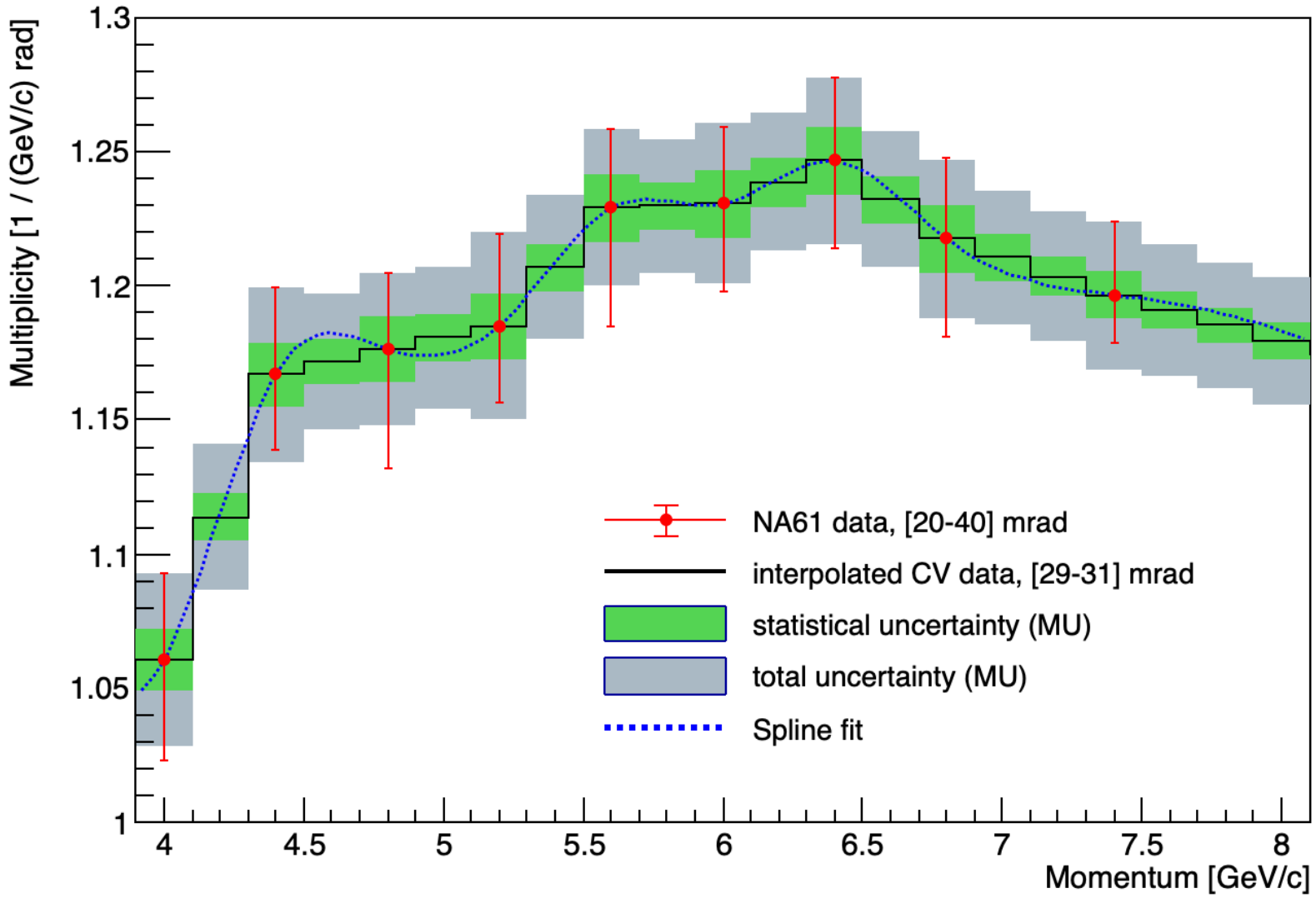






Interpolation of NA61 data for 20-40 mrad:

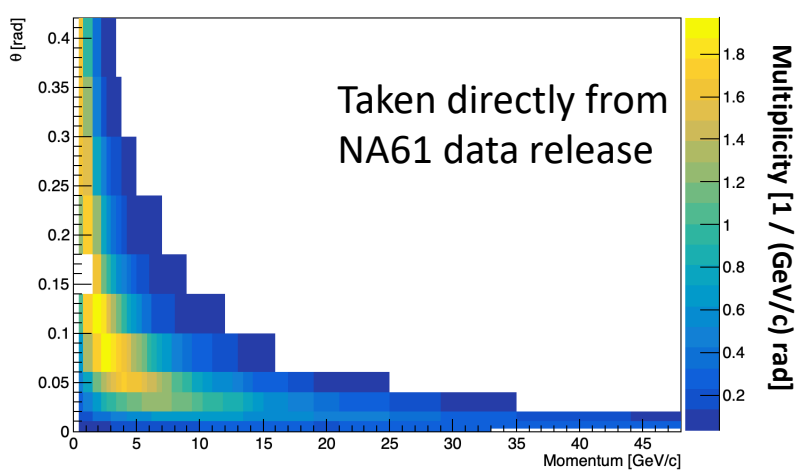
Same plot as in doc-21627.
But this plot includes improved binning:



Reminder

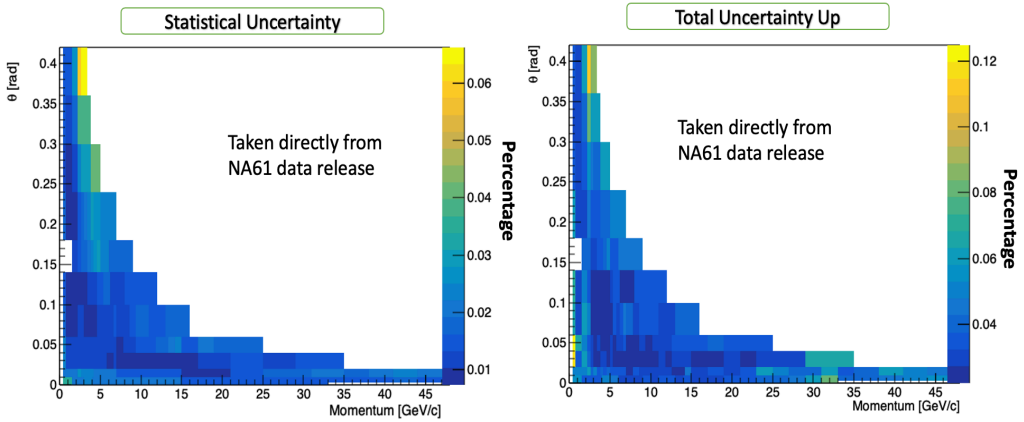
- The central value comes in TH2Poly bins of (θ, P). For instance for the same momentum bin we can have different θ ranges:

Data central value

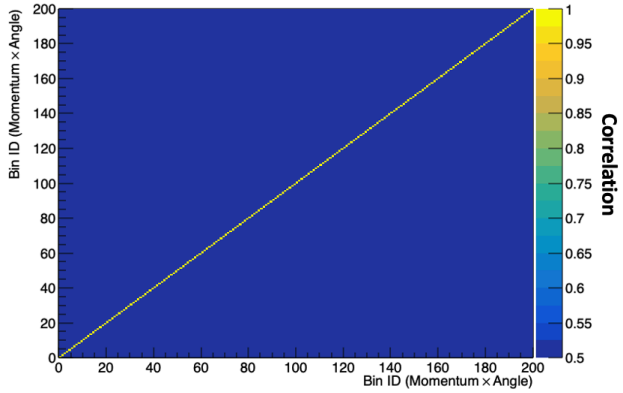


- For statistical uncertainties, random shifts in uncorrelated bins, Gaussian distributed and using the statistical uncertainty, are generated creating new data in 5000 universes in total. We interpolate in each universe.

Data uncertainties: Statistical uncertainty (left), Total uncertainty "Up" (Systematics Up and statistical added in quadrature)



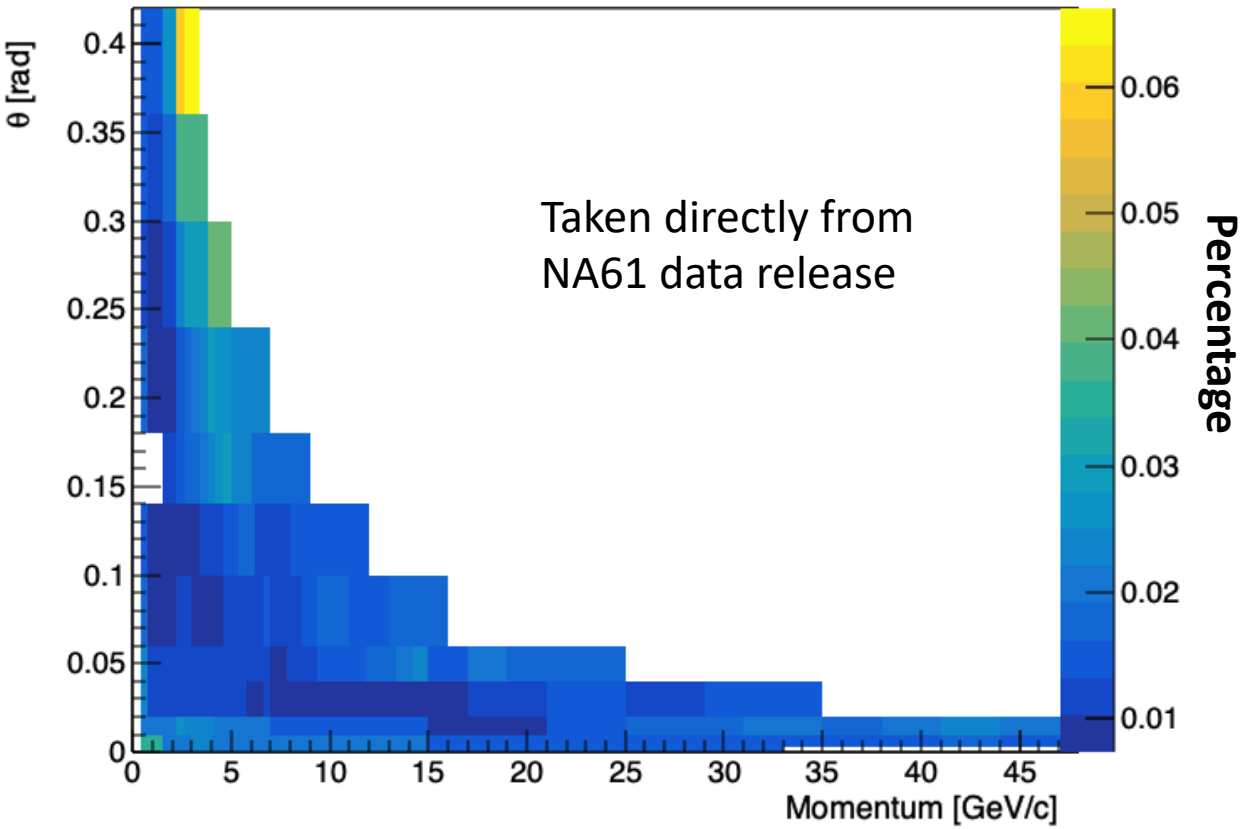
- For systematic uncertainties, the bin-to-bin correlation is not published by NA61. The data release split in systematics coming from different sources and we use **+50% correlation** across all bins as a first attempt.



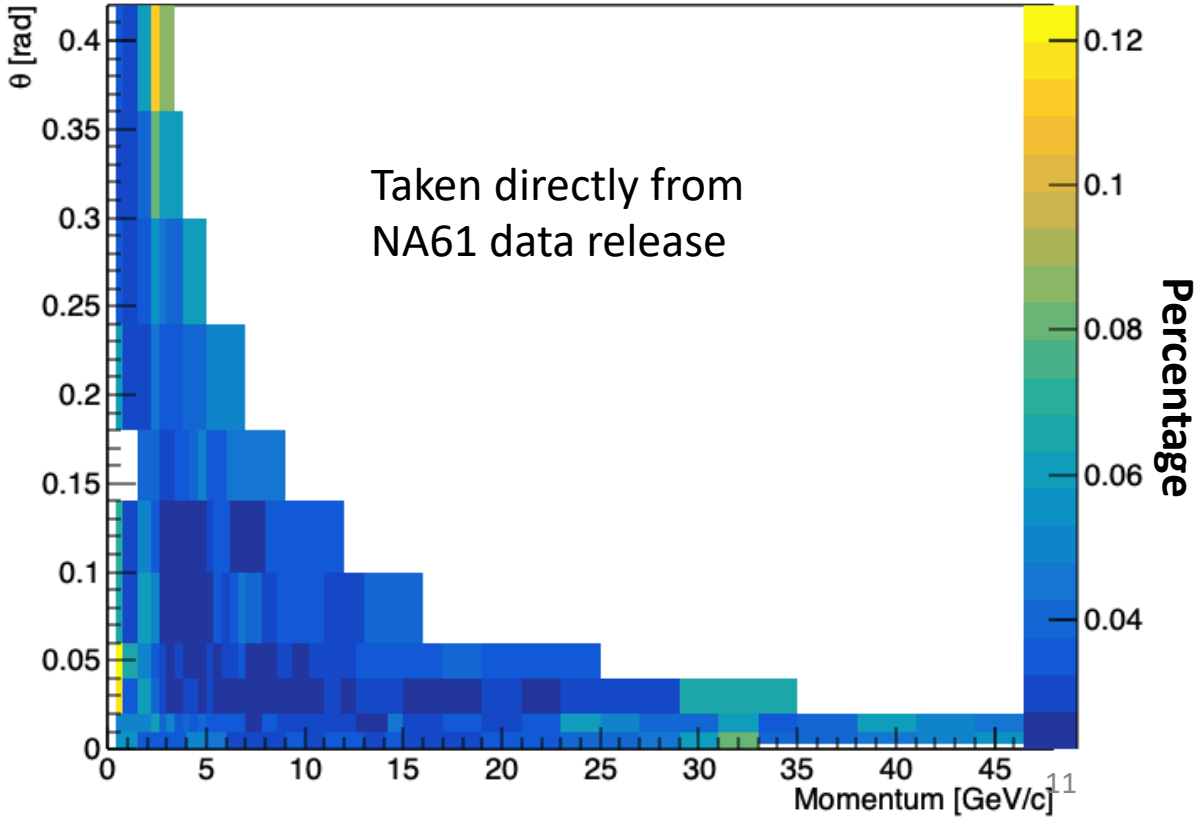
Data uncertainties

- Uncertainties are shown below:
  - Statistical uncertainty (left)
  - Total uncertainty “Up” (Systematics Up and statistical added in quadrature)

Statistical Uncertainty



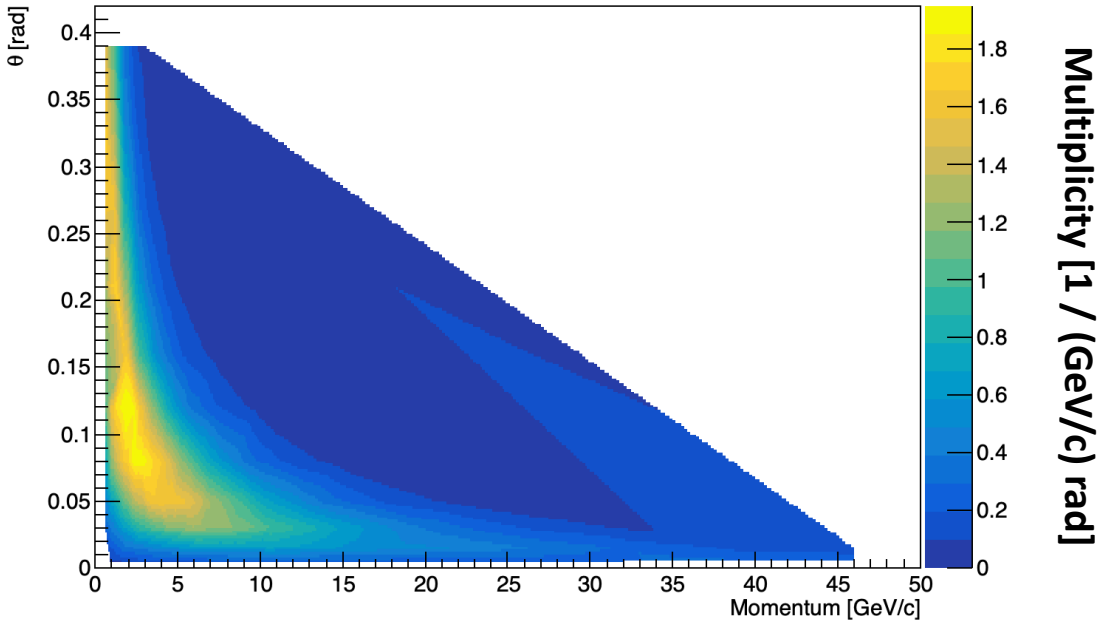
Total Uncertainty Up



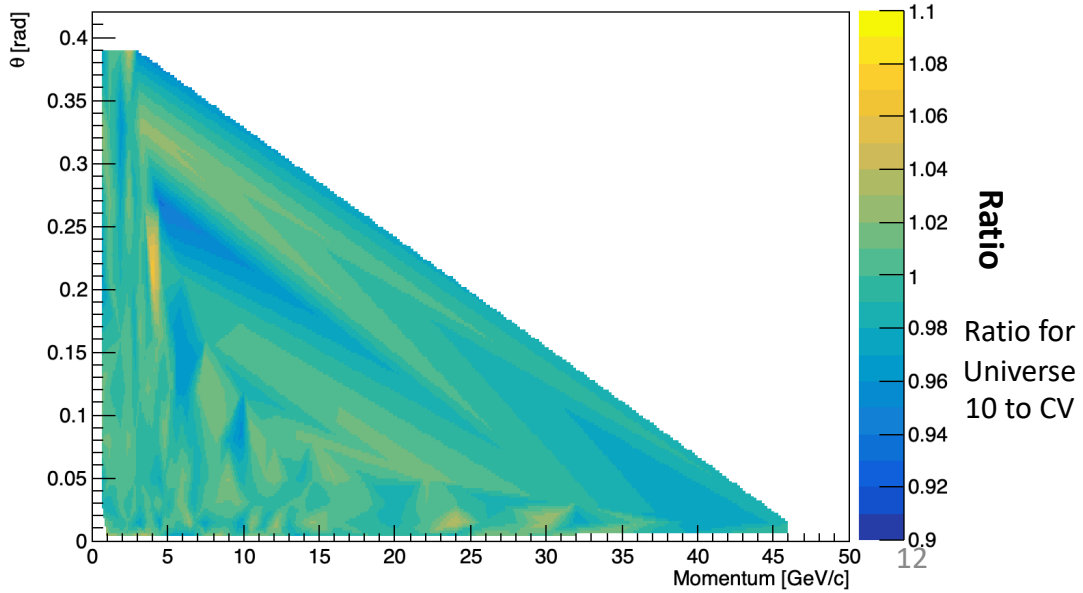
Statistical uncertainties

- We are treated the NA61 statistical and systematic uncertainties independently.
- Random shifts in uncorrelated bins, gaussian distributed and using the statistical uncertainty, are generated creating new data in 5000 universes in total. We interpolate in each universe.
- For instance, for the new data in universe 10:

New CV in universe 10



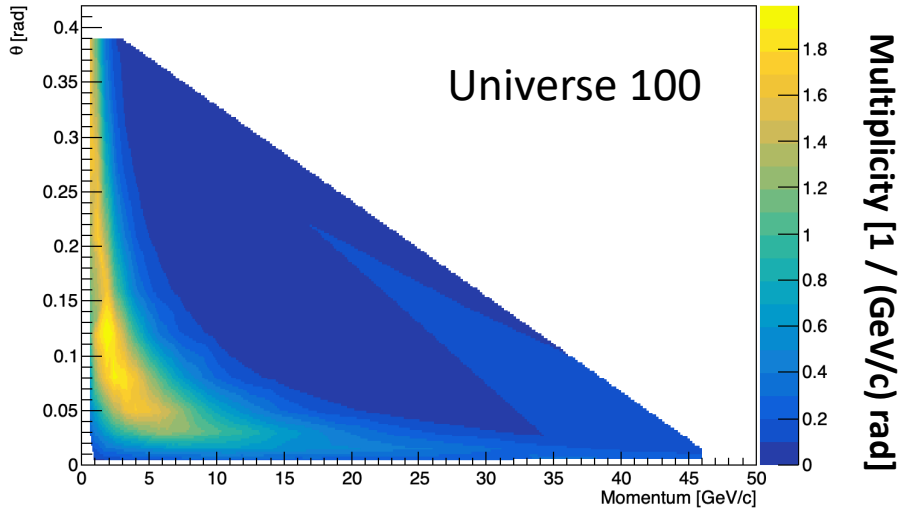
Ratio of the new CV over the nominal

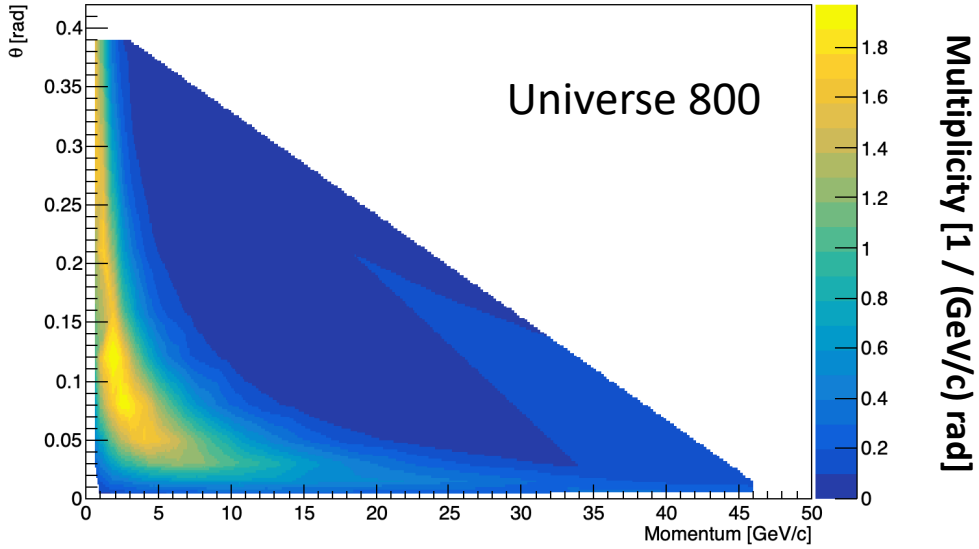


Statistical uncertainties

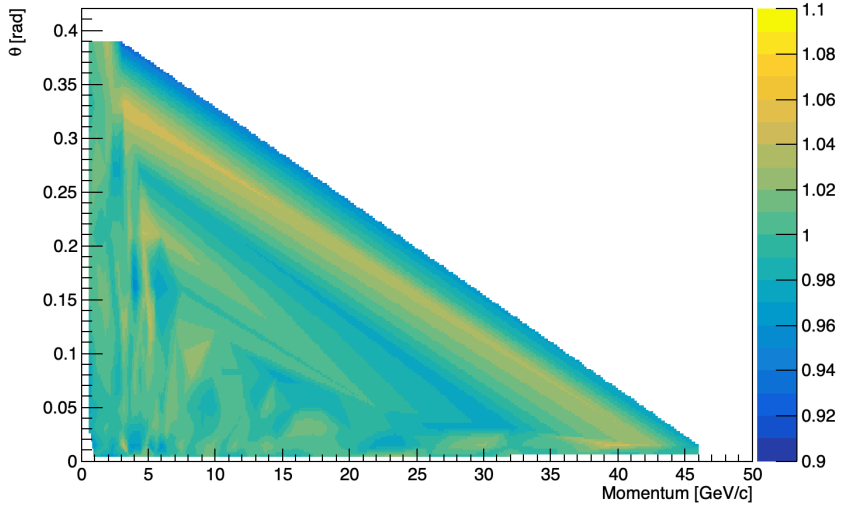
- Other examples:

New CV

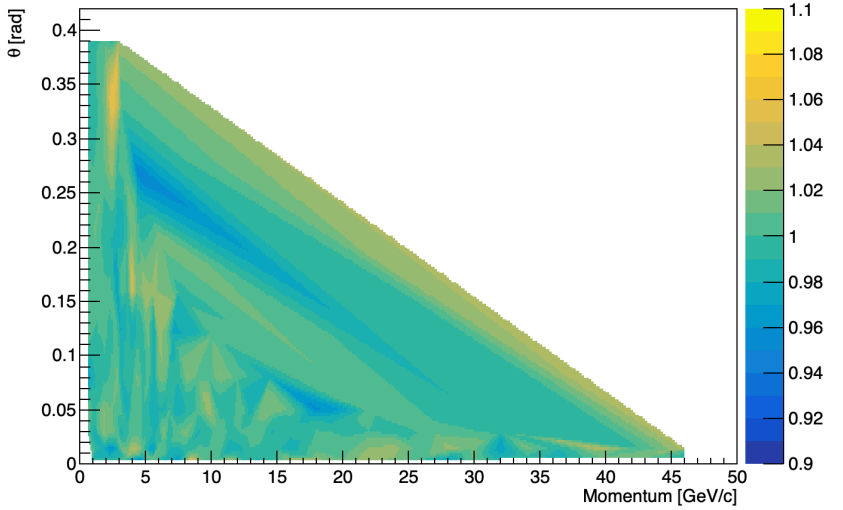




Ratio of the new CV over the nominal



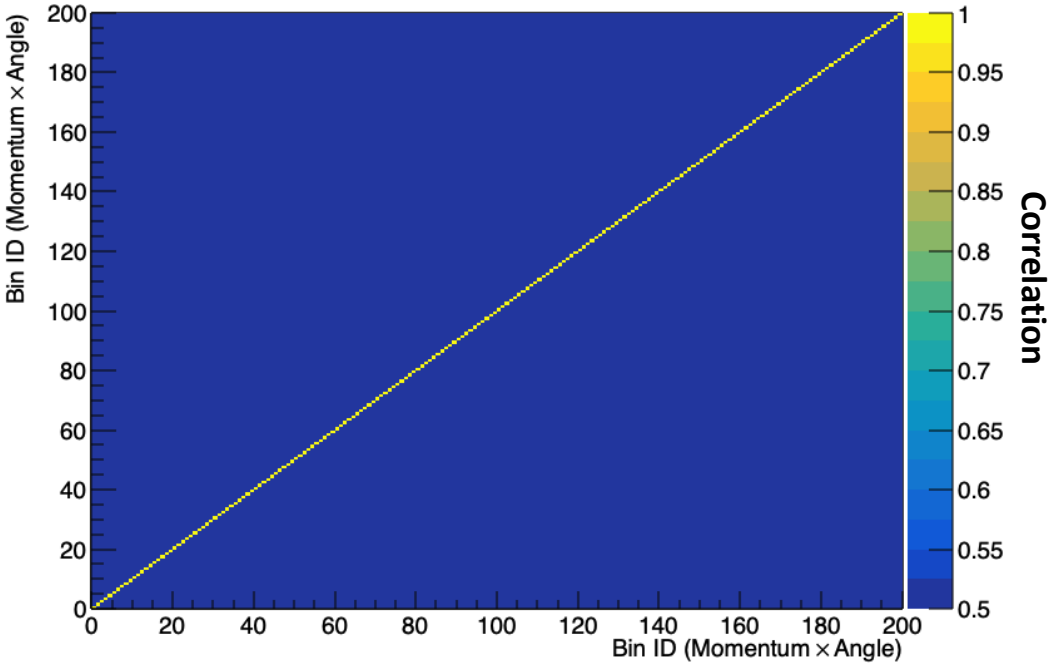
Ratio for Universe 100 to CV

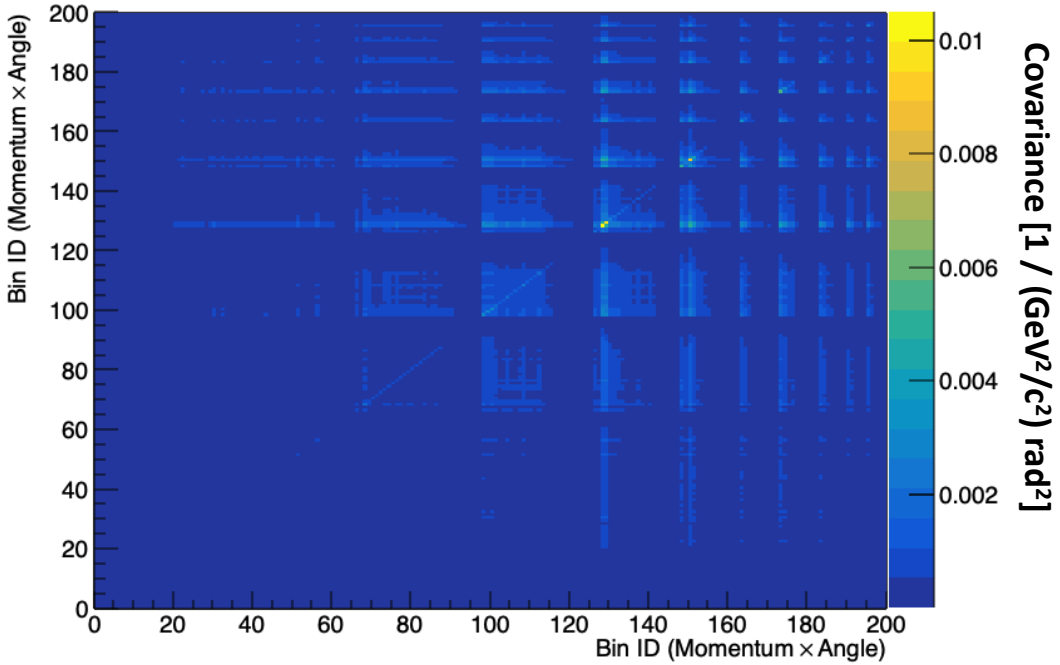


Ratio for Universe 800 to CV

Systematic uncertainties

- The bin-to-bin correlation is not published by NA61. The data release split in systematics coming from different sources.
- We use +50% correlation across all bins as a first attempt (we want to have the infrastructure when we have better values).





- 200 data we have for NA61 in total